SOME PRELIMINARY RESULTS OF PETROLOGICAL WORK IN GALICIA (N.W. SPAIN)

BY

E. DEN TEX

The Spanish region of Galicia is situated in the extreme north-western part of the country due North of Portugal and West of Asturias. It is bordered by the Atlantic Ocean to the West and by the Bay of Biscay to the North (see fig. 1). The area under investigation concerns the western provinces of La Coruña and Pontevedra mainly.

Apart from early reconnaissance work by Schulz (1858), Barrois (1892), Sampelayo (1922), Lotze (1945), Carlé (1945), Navarro and del Valle (1959) the area is at present being investigated and mapped on a scale of 1: 50.000 by López de Azcona, Parga Pondal and their associates for the Instituto Geológico y Minero de España. So far nine sheets and explanatory memoirs have been published between 1948 and 1956. Parga Pondal has also published a geological sketch map on a scale of 1: 400.000 and an explanatory note of the province of La Coruña in 1956, and since 1931 he has contributed substantially to the knowledge of Galician geology in a series of papers concerning petrological, mineralogical, tectonic and sedimentological aspects of it. Between 1955 and 1959 de Sitter and Zwart conducted geological research by the Department of Structural and Applied Geology of the University of Leyden in the area between Lage and Malpica. Summaries of their results appeared in 1955 and 1957, while one of their associates, Insinger, published a short account of his work in the vicinity of Mugía in 1961.

Since 1956 the Department of Petrology and Mineralogy of the University of Leyden, then chaired by W. P. de Roever, is also engaged in detailed mapping and laboratory investigation of certain key areas, rocks and minerals of western Galicia in close co-operation with I. Parga Pondal. When the present author succeeded de Roever in 1959, he inherited his interests in this area with the result that now twenty one students of his department have just finished, or are mapping parts of Galicia on a scale of 1: 25.000 or larger. Their respective field areas have been grouped together and numbered 1 to 5. These group-areas are roughly outlined on fig. 1. The workers are distributed as follows: Area 1: P. A. J. Coelewij, E. Romijn, D. E. Vogel, H. A. de Miranda and J. P. Engels; area 2: H. O. Prade, H. R. P. Rijks, P. Steenstra Toussaint, J. M. M. Fürstner, and F. W. Warnaars; area 3: C. F. Woensdregt, A. F. Koster van Groos, W. P. F. H. de Graaff, P. P. Snoep, I. B. H. M. Rubbens, E. H. von Metzsch, H. G. Avé Lallemant, C. E. S. Arps, I. B. M. ten Bosch; area 4: J. Bezemer; area 5: P. Floor. It is our intention to carry this detailed mapping right through the whole of the Basic Rock Group and the Alkaline Gneiss Group while selected parts of the Migmatic Infrastructure and the Epi-mesozonal Suprastructure will also be covered (see fig. 1). We are fully aware that this work would be much more arduous without the unfailing interest and generous support of Parga Pondal whose knowledge of the area is unsurpassed.

The bedrock of western Galicia is almost entirely crystalline. It consists of

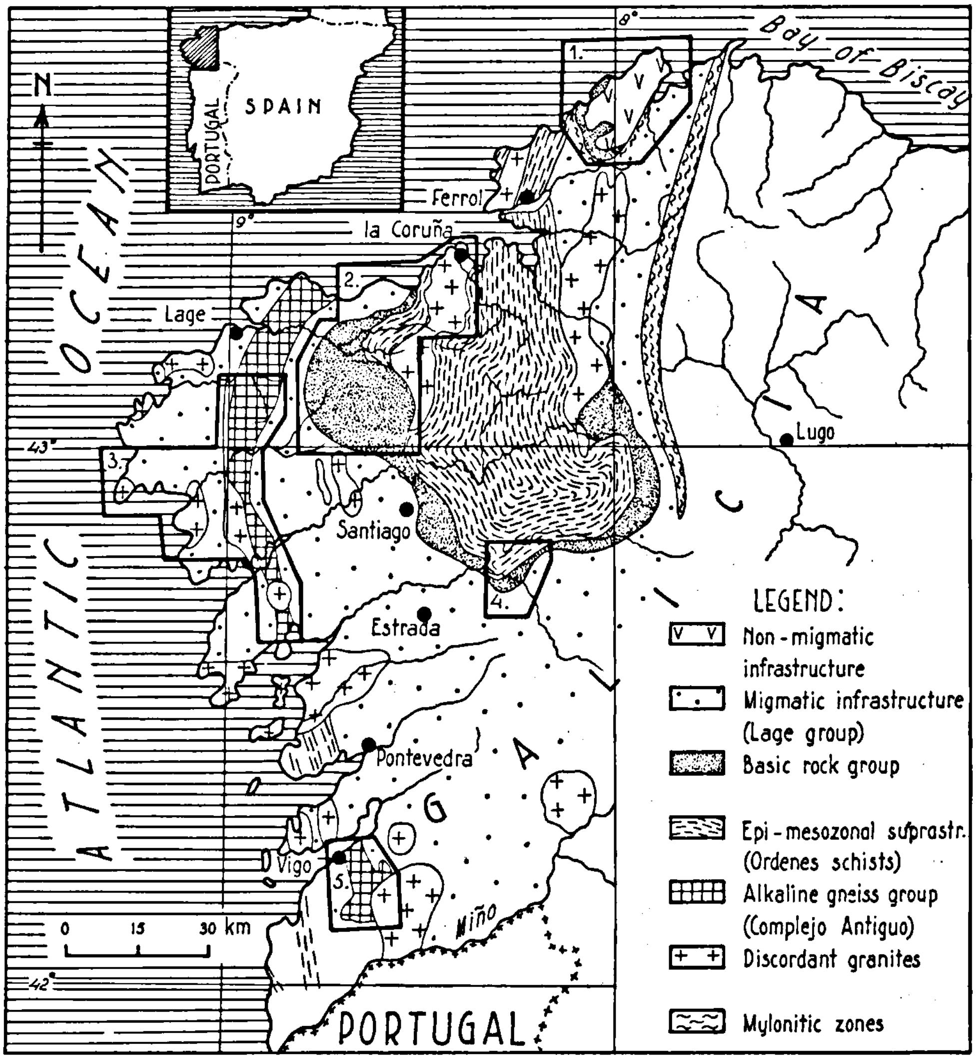


Fig. 1. Geological sketch map of western Galicia showing areas under investigation. After Parga Pondal (1956).

schists, gneisses, granulites, amphibolites, eclogites, gabbros, serpentinites, migmatites, granites and related rocks separated from non- or low-grade metamorphic rocks of Lower Palaezoic age, occurring in the provinces of Lugo and Orense, by a belt of locally mylonitized rocks known as "Ollo de Sapo" (toad's eyes) on account of the many light-coloured fragments it contains. Reliable absolute age determinations are not yet available, while recognizable fossils have not been found in the crystalline rocks of Galicia but, since major angular unconformities with conglomerates carrying pebbles of the crystalline rocks are unknown, the majority of these rocks are considered by most authors to be Palaeozoic and the orogeny responsible for its folding and metamorphism to be Hercynian in age, as is the case in neighbouring Asturias and Portugal. The present author is inclined to agree with Parga Pondal (1956) and Lotze (1956) that it is quite probable that pre-Cambrian rocks are involved in the formation of the Galician basement-complex if only because marbles are so rarely met with in western Galicia whereas limestones are prominent in the unmetamorphosed Palaeozoic sequence.

According to our views the following groups of rocks may be distinguished in what we shall, for convenience, refer to in the sequel as the Galician orogen:

I. The Non-migmatic Infrastructure, the chief outcrop of which is found in northern Galicia, in the area around Cabo Ortegal and Cedeira (see fig. 2).

II. The Migmatic Infrastructure occupying most of S. W. Galicia and scattered areas in northern Galicia. This is the equivalent of Parga Pondal's (1956) Lage Group of schists, gneisses, migmatites and anatectic granites.

III. The Epi-mesozonal Suprastructure, constituting a pear-shaped outcrop within the loop of basic rocks of Group IV, which has been termed Ordenes Schists by Parga Pondal (1956). Similar rocks occur in scattered areas within Groups I, II and V.

IV. The Basic Rock Group forming a semicircular outcrop from Carballo through Monte Castelo, Santiago, Carbia and Mellid to Curtis. Smaller outcrops occur within Groups I, II, III and V.

V. The Alkaline Gneiss Group occurring in the form of a gently curved, discontinuous strip of more or less schistose and gneissose rocks with pronounced alkaline tendencies (albite, riebeckite, aegirine, etc.). It runs from Malpica on the Atlantic Ocean via Zas, Outes and Noya to the Ria de Arosa and is found again between Vigo and Porriño in the Province of Pontevedra. This group with its associated blastomylonitic biotite gneisses corresponds with the Ancient Complex of Parga Pondal (1956).

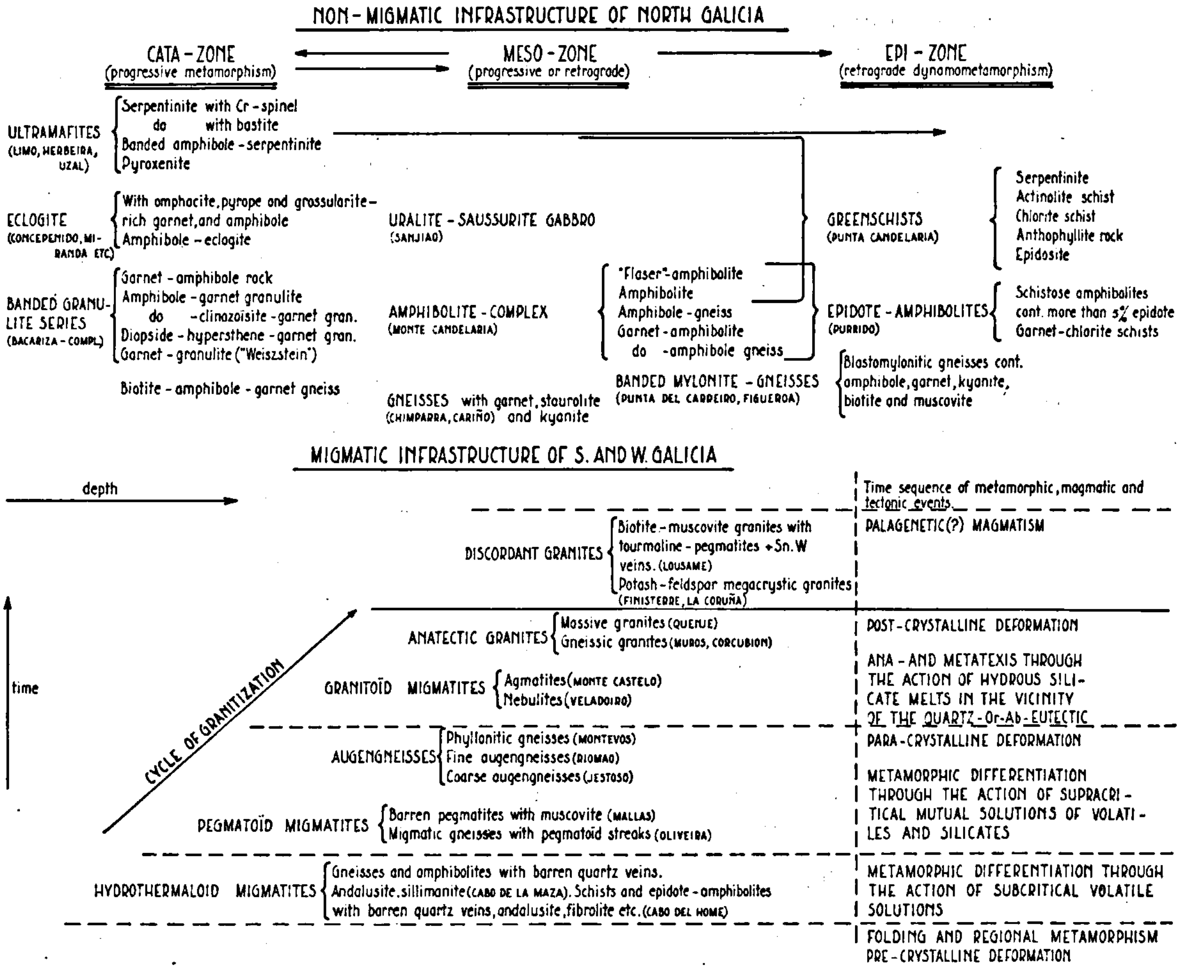
VI. The Discordant Granitic Rocks cutting across rocks of Groups II, III, IV and V in scattered areas of western Galicia. They range from granites s.s. to trondhjemites. They include some of the "non-orientated, homogeneous and porphyritic, late tectonic granites" of Parga Pondal (1956) as well as his "Younger intrusive granites of the Traba type".

This grouping should be regarded as a tentative one, meant to serve only as a framework for a working hypothesis of the Galician Orogen. Except for no. VI being the latest, the numbering of groups does not reflect a sequence in time. In the following paragraphs and in Table I our present knowledge of the various rock groups is summarized. Since the mapping of Group I is most advanced, we shall discuss this group first.

I. NON-MIGMATIC INFRASTRUCTURE

Our surveys in area 1 (see figs 1, 2 and 3) have revealed the presence of a great variety of high-grade metamorphic rocks among which amphibole and pyroxene bearing garnet granulites deserve special mention because, as far as

TABLE I



the author is aware, such rocks have not been reported previously from this part of Spain.

The upper half of Table I shows the more important rock types of this area arranged vertically according to their degree of metamorphism (Grubenmann-Niggli zones), and horizontally on a roughly isochemical basis. In the catazonal column, on the left, rocks ranging in composition from ultramafic dunites (now mostly serpentinized) and pyroxenites to acid garnet granulites are represented.

Granulites were first reported under the name of hornblende gneisses by Coelewij (int. report Leyden University) from the vicinity of Bacariza (see fig. 2). His "Bacariza-complex" was subsequently traced further South and West of the eclogites and banded mylonite gneisses and East of the ultramafic rocks, amphibolites and gneisses by Romijn, de Miranda and Engels (int. reports Leyden University). On a large scale the granulites constitute gentle folds but in detail they are tightly and sometimes disharmonically folded on NNE trending axes (see figs 3 and 4) which is well brought out by the fact that the rocks are distinctly

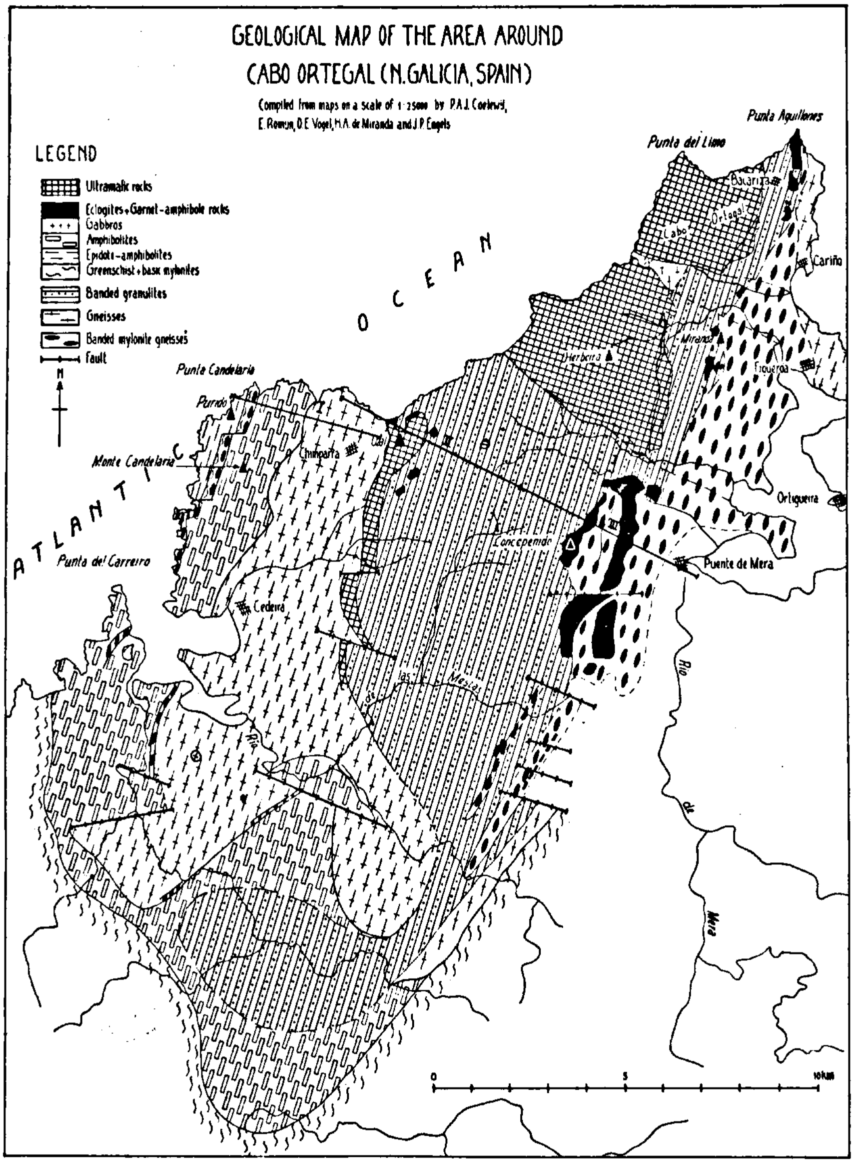


Fig. 2. Geological map of area 1 in fig. 1. The traces of the cross-sections of fig. 3 are numbered I, II and III.

banded in texture (see figs 4 and 5). Individual bands measure from one inch to several feet across their strike and consist of garnet-amphibole rock, amphibole-garnet granulite, amphibole-clinozoïsite-garnet granulite, diopside-hypersthene-garnet granulite (Trapp-granulite of Saxon authors) and acid garnet-granulite ("Weiszstein" of Saxon authors). The latter rock is leucocratic and consists mainly of plagioclase and quartz with garnet and some clinozoïsite as the sole dark constituents (see fig. 5). Generally speaking these rocks appear to be equilibrium assemblages of typomorphic minerals of the granulite facies as defined

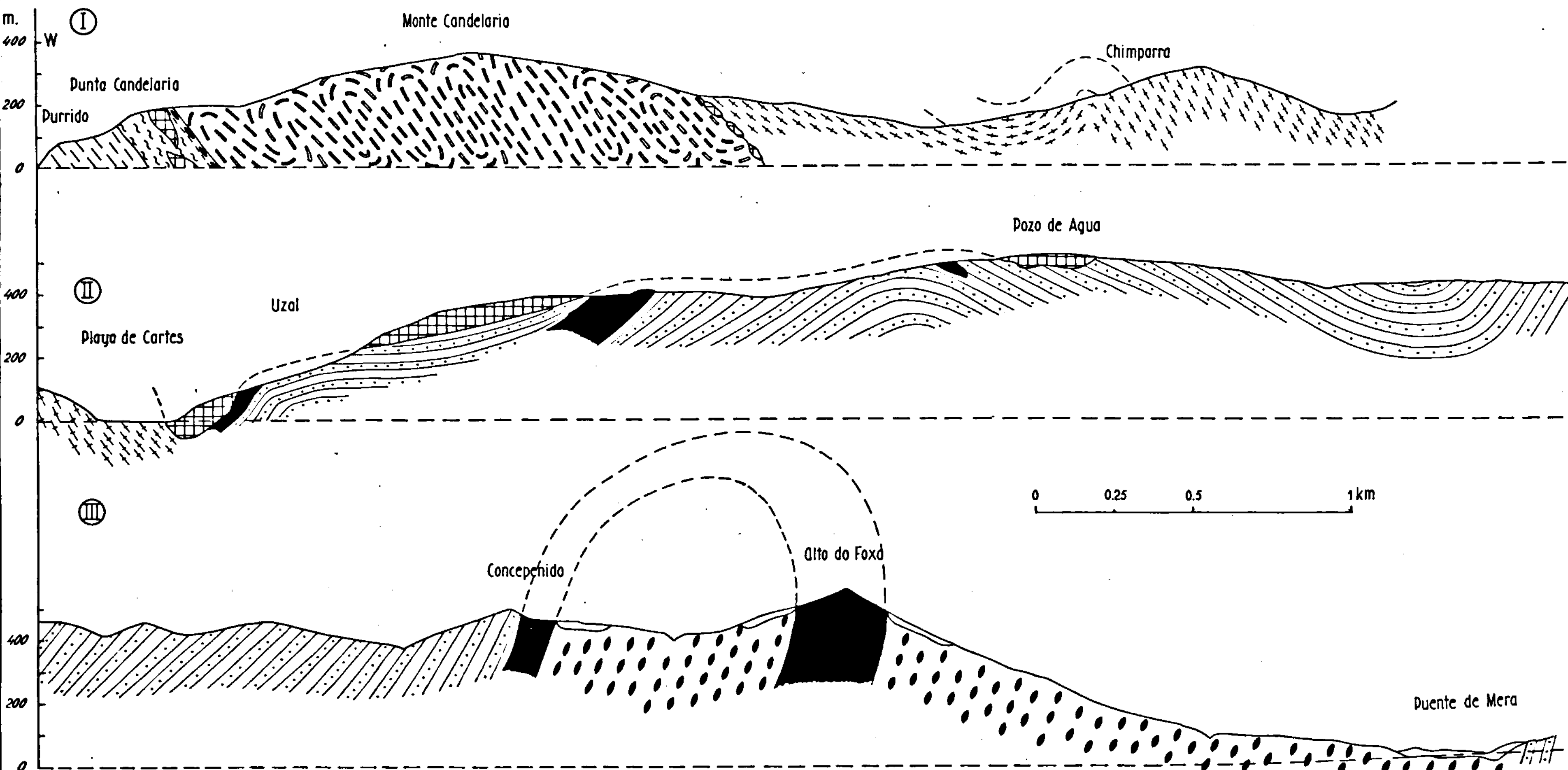
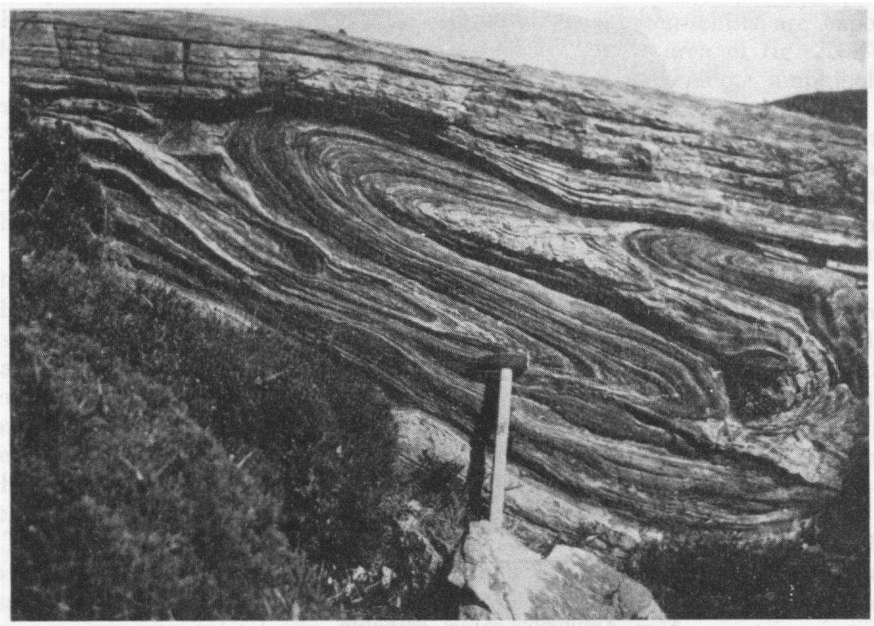


Fig. 3. Cross-sections of the geological map (fig. 2) of the area around Cabo Ortegal and Cedeira. Structures extrapolated from surface-data. For Legend see Fig. 2.

by Turner & Verhoogen (1960). Determinations of the chemical composition of the constituent minerals are still in progress, but their textural relations indicate post- or synkinematic crystallization of the complete paragenesis. The primary amphibole is a brownish green variety in thin section, containing little OH and virtually no F since the chemical analysis of an amphibole-rich granulite (A in fig. 5) yields only 0.57 % combined water on a sum total of 100.44 % exclusive of fluorine. In contradistinction with the green amphibole often found in retrograde eclogites, the brownish green amphibole of the granulites does not exhibit kelyphitic, diablastic or other replacement textures after pyroxene but appears to be in equilibrium with both diopside and hypersthene suggesting conditions of regional metamorphism ranging from the hornblende- to the pyroxene-granulite subfacies of Turner & Verhoogen (1960). Rutile is a constant



Photograph D. E. Vogel.

Fig. 4. Banded granulites gently dipping West, but in detail isoclinally and disharmonically folded on NNE trending axes. South of Teixidelo between the Uzal and the Herbeira in area 1.

accessory in the granulites of Cabo Ortegal. Thin bands and lenses of quartz grains, often elongate parallel to the direction of banding and showing preferred lattice orientation, are common as may be expected in granulitic rocks (see fig. 5). Boudinage of basic bands, including some amphibolites and amphibole bearing eclogites, is a common feature indicating tightly compressed folds, but otherwise the banding is quite regular and well-defined suggesting that the chemical mobility of material, other than possibly hydrous silica, was extremely low.

The main outcrop of eclogite is a steeply inclined layer up to 500 m thick forming a chain of outstanding peaks and ridges such as Aguillon, Monte Castrillon, Miranda and Concepenido. Coelewij (int. report Leyden University) has shown that this layer has been folded isoclinally on an axis plunging 8° in a direction N 16° E. It was subsequently cross-faulted in a sense opposite to that of the axial plunge so that the nose of the eclogitic anticline is repeated several times between the islets off Punta Aguillones and the southernmost outcrop of Sierra de Moles. The eclogites are associations of garnet and pyroxene often with reaction rims of another pyroxene or a green amphibole together with plagioclase. Some eclogites contain abundant amphibole while others have kyanite as a constituent. Rutile is a constant accessory. Optical determinations of garnet and primary pyroxene by Coelewij and quantative chemical analyses of same by Mrs. C. M. de Sitter-Koomans will be published and fully discussed elsewhere. In molecular percentages the garnet has been found to consist of 41 Almandine, 33 Pyrope and 26 Grossular. This is a garnet composition consistent with that

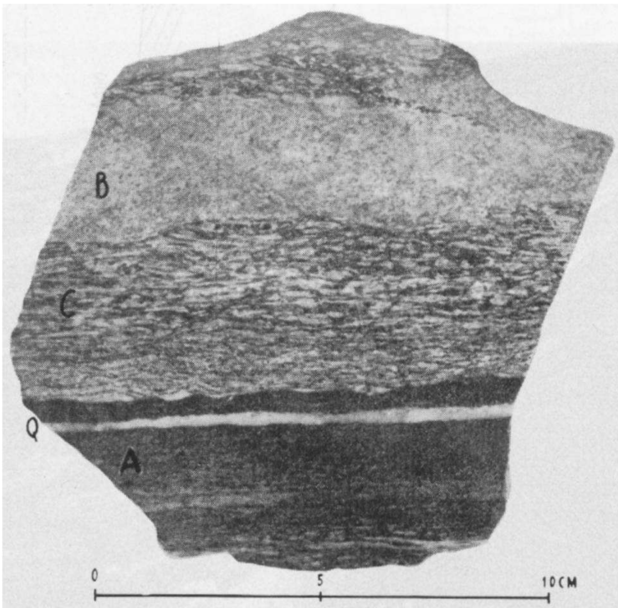


Fig. 5 Banded granulite from Francoy near Puente de Mera (area 1)
A = Amphibole-garnet granulite
B = garnet granulite („Weiszstein")
C = amphibole-clinozoïsite-garnet granulite
Q = quartz lamina

of the average eclogite according to Tröger (1959). Similarly, the primary pyroxene containing 15 Jadeite, 11 Acmite and 74 Diopside is a true eclogite-pyroxene or omphacite according to Tilley's (1937) and von Wolff's (1942) data. Thus the primary paragenesis is an equilibrium association of critical minerals of the eclogite facies as defined by Eskola (1921). If the average eclogite of Cabo Ortegal is assumed to be composed of equal proportions of the said garnet and pyroxene, then certain heteromorphic assemblages may be calculated as follows:

10 Garnet + 10 Pyroxene = 7 Ca-Aug(Di_1He_1) + 11 Ol(Fo_6Fa_5) + 11 Plag(An_{75}) + 1 Nef.
(eclogite) (alkali-olivine basalt)

10 Garnet + 10 Pyroxene = 5 Plag(An_{40}) + 6 Amphibole ($Cé_1$ Ts_2 $Trem_9$.)
(eclogite) (amphibolite)

Thus, the supposition that the eclogites have resulted from progressive regional metamorphism of either basaltic or amphibolitic rocks or that the latter are the products of retrograde metamorphism of eclogites or basaltic rocks, is strengthened by the isochemical nature of these processes. In fact, Romijn (int. report Leyden University) has observed in some eclogite-garnets inclusions of pyroxene and plagioclase which may represent armoured relics of basaltic or gabbroic rock, while Vogel and Engels (int. reports Leyden Univ.) have reported bodies of incompletely retromorphosed eclogite, granulite and hornblende-gabbro in the amphibolites of Monte Candelaria, Sanjiao etc. It is, of course, to be expected that relics of retrograde metamorphism are much more abundant than those that have survived progressive metamorphism especially under such high temperatures and pressures as would prevail in the eclogite or granulite facies.

Amphibolites, amphibole gneisses (containing more than 5 % quartz), epidote amphibolites (containing more than 5 % epidote) and green-schists are exposed in close association in the extreme West and South of the area of fig. 2. They may be thinly banded or foliated or — in the case of the epidote amphibolites of the Purrido — downright schistose. Their average dip is 60° to the ESE but like the granulites and eclogites they appear to be isoclinally folded in detail. Garnet is locally an important constituent and if this mineral becomes sufficiently enriched in a dark band a garnet-amphibole rock is the result. Although some amphibolites, especially those with "Flaser"-textures of hornblende and those with inclusions of gabbro, are to all probability ortho-amphibolites, derived from basalts, dolerites or gabbros, this does not mean that others — for instance the amphibole gneisses — may not be para-amphibolites derived from dolomitic marls, basic graywackes or granulites. The intimate association of amphibolites and amphibole gneisses on the one hand and of eclogites and granulites on the other is perhaps significant, and attempts to correlate these associations with each other by means of comparative chemical and fabric analyses are in progress. In this context the field relations between amphibolite and granulite in the extreme South of the area of fig. 2 are of great importance and will be studied in more detail.

The junction between foliated amphibolites and schistose epidote amphibolites from Punta Candelaria to the SSW is formed by a zone of banded mylonite gneisses and tectonic "fish" including mechanical lenses and boudins of dunite, pyroxenite, serpentinite, eclogite, granulite and epidosite set in a matrix of green-schist and exhibiting tension-gashes filled with plagioclase, anthophyllite, epidote, calcite, adularia etc. Widespread recrystallization and neomineralization has tended to obscure the cataclastic texture of these blastomylonites, except certain porphyroclasts of amphibole and feldspar, suggesting that the dislocation in this zone occurred at fairly high temperatures, probably in the deeper levels of the crust, and not much later than the folding and regional metamorphism of the infrastructure. A similar, but broader zone of less basic, banded mylonite gneisses occurs East of the chief eclogite outcrop and has been formed mainly at the expense of granulitic and gneissic rocks. A typical section is exposed on the shore of the Ria de Santa Marta de Ortigueira near Figueroa.

Micaceous gneisses containing garnet, plagioclase, potashfeldspar and sometimes kyanite or staurolite occur between the chief granulite and amphibolite outcrops around Chimparra and Cedeira and also in the extreme NE of the area, near Cariño. Like the amphibolites they are mesozonal rocks dipping generally ESE at rather high angles, but some dip reversals and more gentle inclinations indicate that isoclinal folding has affected the gneisses also. From a chemical point of view they have no equivalents in the catazonal column apart from thin bands of garnet granulite and biotite-amphibole-garnet gneiss.

Serpentinites, pyroxenites and other ultramafic rocks form three main outcrops at the Western extremity of the granulites and — in the case of the body exposed on the Uzal — at the Eastern margin of the gneisses. The latter body dips gently West (see fig. 3) while those on the Herbeira and SW of Punta del Limo are almost horizontally disposed, in concordance with the major structure of granulites and gneisses in this area. There is no indication whatever that the emplacement of these larger ultramafic bodies was one of a primary tectonic nature. They appear to have been folded along with the neighbouring rocks but perhaps squeezed out in the steep limbs of major folds and accumulated in the hinges of major synclines and anticlines. They are accompanied by minor bodies and veins of garnet-pyroxene-amphibole rock: perhaps the basic products of eclogitic or granulitic metamorphism of which the true dunites are probably not susceptible being chiefly associations of olivines and spinellids which remain stable at the highest temperatures and pressures prevailing in the earth's crust.

To the South the Non-migmatic Infrastructure is delimited from the Migmatic Infrastructure by a zone of greenschists and basic mylonites of the secondary type as defined by Christie (1960). Where gneisses are involved in this high-level dislocation the aspect of the rocks may become phyllonitic.

II. MIGMATIC INFRASTRUCTURE

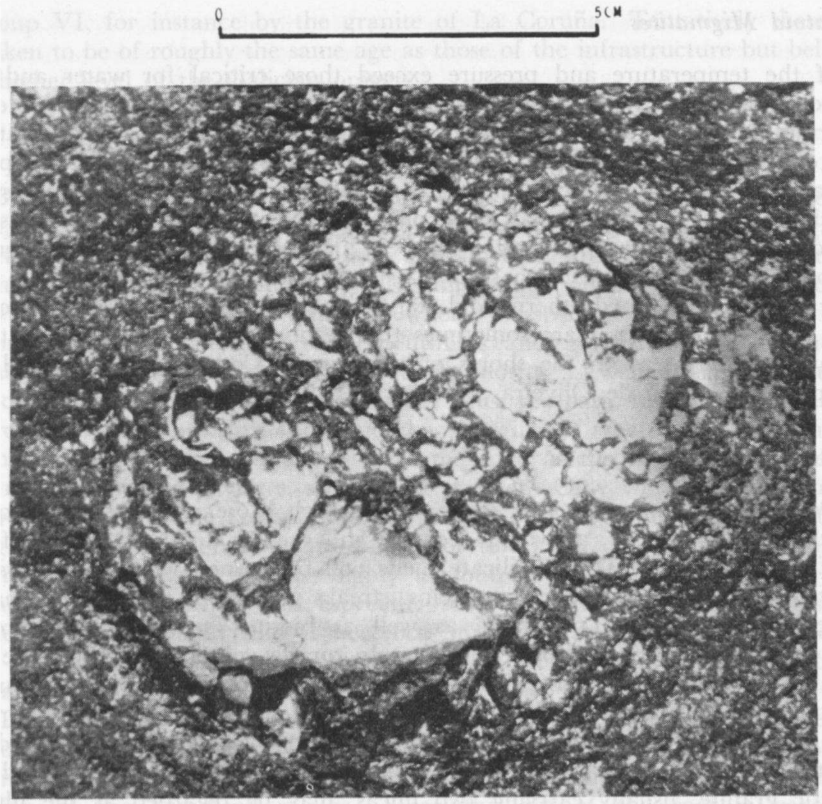
In areas 2, 3 and 4 of fig. 1 there are extensive outcrops of schists, gneisses, migmatites and anatectic granites belonging to Parga Pondal's (1956) Lage Group. Characteristically the rocks of this group exhibit features of metamorphic differentiation, selective mobilization, metatexis, anatexis and granitization. This serves to distinguish them from all other rock groups of the Galician orogen and hence the name Migmatic Infrastructure was coined for this group (see Table I).

Ordinary schists and gneisses are subordinate in occurrence. They are highly micaceous and contain both plagioclase and potash-feldspar. When alumosilicates are present, they are usually andalusite or sillimanite (variety fibrolite) and seldom kyanite, suggesting that the temperature gradient of metamorphism was steep. Amphibolites are occasionally interstratified often as discontinuous layers, lenses or boudins. The strike varies from NW to North and the dip is generally steep but variable in sense.

Migmatites constitute the bulk of this group of rocks and they may be subdivided according to the nature of the mobilized fraction as was recently proposed by Mehnert (1960):

Hydrothermaloid Migmatites

In the presence of excess water at subcritical temperatures and pressures silica and alumosilicates may be dissolved and re-deposited in areas of low stress. Thus lumps and veins of coarse-grained milky quartz as well as large crystals of andalusite and sillimanite may develop to give the rock a migmatic aspect. Barren quartz-veining is especially prominent in certain schists and gneisses often far distant from outcrops of granitic rocks as between Louredo and Pajareizos and on Playa de Louro, near Muros, in area 3 (see fig. 7).



Photograph A. F. Koster van Groos.

Fig. 6. Spongy porphyroblast of potash-feldspar in pegmatoid migmatite near Castillo del Principe, Ria de Corcubion (area 3)

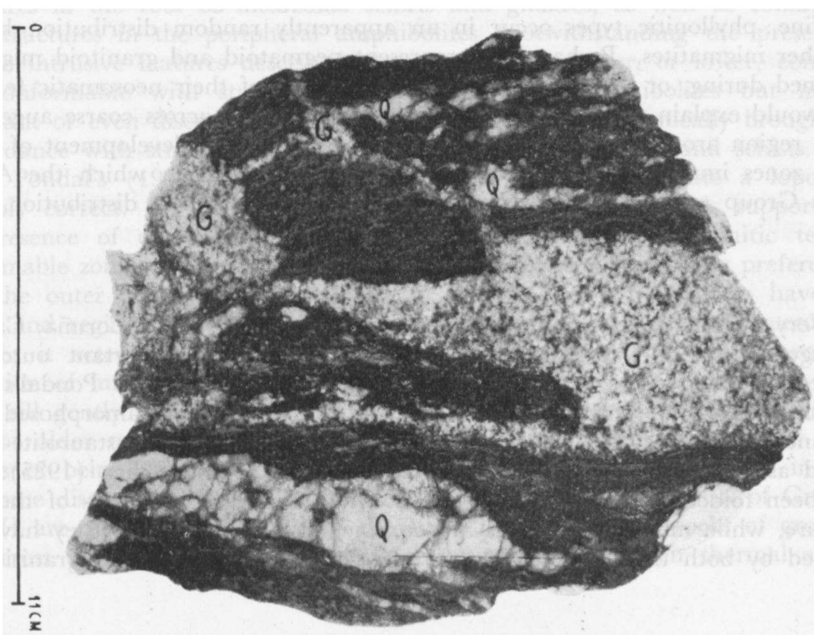


Fig. 7. Migmatite showing schistose relics (dark fragments) cut by hydrothermaloid quartz veins (Q) and these, in turn, cut by granitoid veins and portions (G). Telescoped sequence of selective mobilization. Agmatitic structure. Playa de Louro near Muros in area 3.

Pegmatoid Migmatites

If the temperature and pressure exceed those critical for water and other common volatiles in rocks, highly variable mutual solutions of such volatiles and of certain alkali-alumosilicates are formed which may also be precipitated in areas of low stress. Thus the development of large spongy crystals of potash-feldspar, sometimes graphically intergrown with quartz, in schists, gneisses or hydrothermaloid migmatites may be explained. Eventually albite and muscovite may join the mobile fraction and patches or irregular veins of barren pegmatite may be formed which are often seen to cut across quartz veins belonging to the earlier and shallower hydrothermaloid stage. The original structures and textures of the schists and gneisses are sometimes thoroughly disrupted and permeated by pegmatitic material as on the shores of the Ria de Corcubion near Castillo del Principe and Castillo de Oliveira.

Granitoid Migmatites

When the temperature and pressure approach those of the hydrous quartz-orthoclase-albite eutectic, as would occur at still greater depth or upon a further rise of the geo-isotherms, then silicate melts will be formed which may crystallize in apropriate places to give rise to veins, streaks and small portions of anatectic granite often containing muscovite as well as biotite (see fig. 7). Here, the granitic veins are cutting across earlier barren quartz veins, while elsewhere large pegmatitic crystals of potash-feldspar appear to be corroded by the surrounding granitoid fraction. In fig. 7 the disrupted portions of gneiss create the impression of an agmatite but near Veladoiro, in area 3, the rock is better described as a nebulite showing "ghost-stratification" of schistose remnants. Large bodies of anatectic granite, usually carrying two micas, may be regarded as the ultimate products of granitization, containing occasional remnants of schist or gneiss only. When gneissose, these granites often trend distinctly East of the schists and gneisses surrounding them.

Augengneisses with eyes of potash-feldspar ranging in grain size from coarse to very fine, phyllonitic types occur in an apparently random distribution between the other migmatites. Perhaps they represent pegmatoid and granitoid migmatites deformed during, or shortly after, the crystallization of their neosomatic feldspars. This would explain why fine augengneiss appears to cut across coarse augengneiss in the region around Riomao and Jestoso in area 3. The development of augen-gneiss zones immediately adjoining the postulated graben in which the Alkaline Gneiss Group occurs, is another conspicuous feature of their distribution.

III. EPI-MESOZONAL SUPRASTRUCTURE

Very little work has yet been done in the area between La Coruña, Carballo, Santiago, Lalin, Mellid and El Ferrol where the most important outcrop of phyllites, schists, gneisses and amphibolites belonging to Parga Pondal's group of Ordenes Schists occurs. The rocks appear to have been metamorphosed in the epi- and mesozones of Grubenmann-Niggli (1924) up to the staurolite-kyanite isograd as defined for pelitic rocks by Barrow (1912) and Tilley (1925). They have been folded in a more open manner than the adjoining rocks of the infra-structure, while migmatic features are conspicuously absent. Yet, they have been intruded by both the basic rocks of group IV and the discordant granitic rocks of group VI, for instance by the granite of La Coruña. Tentatively these rocks are taken to be of roughly the same age as those of the infrastructure but belonging to a higher level of the Galician orogen.

IV. BASIC ROCK GROUP

Between the Migmatic Infrastructure and the Suprastructure there occurs a broad, slightly discontinuous, horizon of predominantly basic rocks such as gabbros, dolerites, norites, amphibolites, epidote amphibolites, greenschists, pyroxenites and serpentinites. The true thickness of this semi-circular outcrop reaches a maximum of 10 km to the North of Santiago where massive gabbro forms the central portion fringed by amphibolites, serpentinites and greenschists, and containing probably contaminated portions of cordierite-norite as well as slivers of contact altered or perhaps even assimilated schist. Thus, the basic rocks are intrusive into the rocks of the suprastructure but the margins of the body were probably metamorphosed to amphibolites at the same time as the neighbouring sediments were made over into phyllites, schists and gneisses. Only where the igneous body was very thick, did the central portion possibly stay fluid (or at least hot) long enough to escape regional metamorphism of this kind. The outer junction with the migmatic infrastructure is highly tectonized often with secondary shear-folding of the schistosity, and especially so where the basic rocks are severely pinched, with the result that it becomes impossible to judge whether the basic rocks were intrusive into the infrastructure or were brought into juxtaposition mechanically.

This seems to infer that the "pinch- and swell" structure of the main outcrop of basic rock (see fig. 1) is primarily a tectonic feature due to transcurrent movements on shear planes obliquely cutting the primary schistosity and foliation of the basement groups. Since the dip of the roof is gentle and centripetally arranged with respect to the approximately circular shape of the outcrop, the body of basic rock may be said to occupy a basin or a shallow syncline plunging North. Moreover its upper contact is roughly concordant with structures in the roof of mesozonal schists and gneisses, as well as conformable with structures in the peripheral amphibolites (notwithstanding the presence of definite intrusive features described above) while the outer, or lower, contact is also conformable with structures in the peripheral amphibolites but may be accordant or even discordant (as North of Silleda) or mechanically brought into concordance with structures in the migmatic granites, gneisses and schists. Thus Parga Pondal's (1956) suggestion that the basic rocks constitute a lopolith is probably correct. Its crystallization and differentiation *in situ* is supported by the presence of contactmetamorphic phenomena, doleritic or ophitic textures, conformable zoning of rock-types and occurrence of ultrabasic bodies preferentially near the outer or lower contact. The basic rock group appears to have been folded and regionally metamorphosed along with rocks of the suprastructure but whether it acted as a horizon of disharmonic folding in the simultaneous deformation of infra- and suprastructure, or that it constitutes a true intra-formational sill gently folded into a lopolith and locally pinched-out between a rigid floor of older migmatites and a more plastic roof of younger sediments in the process of being metamorphosed, remains to be decided by the work in hand.

Some discordant granitic rocks intrusive into gneisses and schists of Group II and III are also seen to cut across the structure of the basic rocks of group IV and across the contacts between the three groups. Within their thermal aureoles unoriented and undeformed andalusite and chloritoid may be developed with helycitic textures exhibiting the secondary plications of the schistosity and foliation.

V. ALKALINE GNEISS GROUP

In 1945 Carlé mentioned the presence of a discontinuous belt of concordant biotite gneisses, amphibolites, micaschists and phyllites between Vigo and Malpica some 35 km West of La Coruña (see fig. 1). López de Azcona (1953) and Parga Pondal (1956) recognized pyroxenites, eclogites, riebeckite-aegirine and biotite-hornblende gneisses within this belt which is slightly convex to the West, 80 km long and in the average 6 km wide, and which Parga Pondal has labelled Ancient Complex because of its alleged poly-metamorphic nature and higher grade of metamorphism originally. Zwart (1957) reported massive granites in what he called the Linear Gneiss Group, which is closely associated with the Alkaline Gneiss Group. More alkaline gneisses were recorded by P. Floor from the vicinity of Vigo (int. report Leyden University) constituting a slightly discordant mass resembling a deformed central complex of semicircular outcrop. Recently hornfelsic rocks containing cordierite, and gneisses with stilpnomelane and a glaucophane-like amphibole have been reported from a number of localities which are being investigated by our fieldgroups in area 2 and in the eastern part of area 3 (see fig. 1).

Except for the eclogites and the alkaline gneisses proper, the rocks of Group V closely resemble those of Groups III and IV. A further apparent coincidence between these Groups is the utter paucity of migmatites and other features of granitization, which are so abundant in the surrounding rocks of the infrastructure. The name Alkaline Gneiss Group has been coined to give proper relief to the most distinctive feature of the rocks within this belt. However, we are aware that the alkaline gneisses may be much younger than the rocks resembling those of the Epi-mesozonal Suprastructure and adjoining lopolith and that, if the latter correlation should prove to be correct, Group V cannot possibly be older than the Migmatic Infrastructure but is either contemporaneous with it (representing a higher level of erosion) or even younger. Should they indeed belong to the Epi-mesozonal Suprastructure of the Galician orogen, then their occurrence in what is nearly everywhere a topographic depression in the middle of steeply dipping gneisses and migmatites of the infrastructure can only be explained satisfactorily by their downfaulting in a major graben. The following additional evidence may be brought forward in support of the graben-hypothesis:

(I) Outcrop in the form of a belt of great length (more than 80 km) and rather constant width (average 6 km);

(II) Somewhat rectilinear, highly tectonized and nearly everywhere steeply inward dipping boundaries to the West and East, sometimes involving zones of phyllonitized gneiss and schists with shearfolded schistosity;

(III) Within the belt schistosity and foliation are not everywhere conformable to the boundaries. There is a pronounced tendency for the dips of these structures to be directed gently inward. However, they are locally steepened to conform with the dip of shear zones, especially those forming the boundaries of the complex. Thus, the interior structure of the belt is comparable to a broad synclinal trough which may well have been caused or accentuated by its subsidence with drag along the boundary faults;

(IV) Occurrence within the belt of a profusion of alkaline rocks, cut by faults subparallel to the boundaries of the belt and extremely rare in the country outside (cf. Oslo-Graben). These rocks, though later than their immediate country-rocks and probably contemporaneous with the subsidence of the belt, are gneissose and slightly metamorphic suggesting that orogenic stresses were active in this area in two distinct periods separated by a period of tension in which alkaline rocks were intruded into a subsiding trough. The later phase of deformation may have been responsible for the curvature of the belt and may have been connected with the emplacement of some discordant granitic rocks of Group VI which are cutting clean across parts or all of the alkaline gneiss belt superimposing effects of thermal metamorphism on those of low, often retrograde, regional metamorphism mentioned above.

VI. DISCORDANT GRANITIC ROCKS

Discordant bodies of more or less massive hypabyssal and plutonic rocks are distributed in an apparently random manner over most of Galicia (see fig. 1). According to Parga Pondal (1956) they range from trondhjemites (tonalites or quartzdiorites) through granodiorites and syenites to granites and quartz-porphyrites.

For the sake of convenience they have here been grouped together as the discordant granitic rocks of Galicia, but no implication as to their general contemporaneity or common genesis is intended therewith. Although the long diameters of the plutonic outcrops are often of meridional trend, i. e. approximately concordant with the trend of other basement structures, they are on a smaller scale definitely cutting across the schistosity and foliation of schists, gneisses and amphibolites, and have induced effects of thermal metamorphism in them. Also, preferred orientation of constituent minerals and xenoliths, when present, is everywhere conformable with the local margin of the plutonic body suggesting that an intrusive magma containing suspended crystals and xenoliths of earlier formations has developed a primary flow structure.

Our present investigations are concerned chiefly with the granite of La Coruña in area 2, the Pindo, Pando and Finisterre granites and the granite of La Ruña in area 3. Of these the La Coruña, Pindo and La Ruña granites are probably of the central complex type being composed of a more or less continuous marginal ring of biotite-rich granite or granodiorite often containing megacrysts of potash-feldspar and an inner core of even-grained, muscovite rich granite. They are often cut by tourmaline bearing pegmatites which, in turn, may be dissected by quartz veins carrying tourmaline, cassiterite, wolframite, molybdenite, tantalite, monazite and other ore minerals of the pneumatolytic Sn - W - Mo paragnesis. This typically magmatic suite is the reverse of the sequence of hydrothermaloid followed by pegmatoid followed by granitoid bodies as observed in the migmatic rocks of Group II, which may be regarded as characteristic of granitization processes. Moreover the chemical analyses available *ad hoc* indicate that the Na : K ratio of some discordant granites is approximately half of that prevailing in the anatectic granites and augengneisses of Group II.

Although discordant granitic rocks are obviously the latest crystalline formations in the area, their absolute age remains a matter for conjecture. Parga Pondal (1953, 1956) distinguishes between Hercynian and Tertiary granitic rocks while Navarro and del Valle (1959) differentiate between syntectonic and late tectonic

Hercynian granites separated by a phase of migmatization, but the evidence quoted in support is open to severe criticism. We have therefore embarked on an extensive program of isotopic age determinations of concordant as well as discordant granitic rocks occurring in structural key positions. For this purpose we have been fortunate to secure the collaboration of the Geochronological Research Group attached to the Laboratory for Mass separation of the Netherlands Foundation for the Fundamental Investigation of Matter (FOM) at Amsterdam.

REFERENCES

BARROIS, CH., 1882. Recherches sur les terrains anciens des Asturies et de la Galice, Mem. Soc. Géol. du Nord, Lille, t. 2, Mem. 1.

BARROW, G., 1912. On the Geology of lower Dee-side and the southern Highland border, Proc. Geol. Assoc. London, vol. 23, pp. 274—90.

CARLÉ, W., 1945. Ergebnisse geologischer Untersuchungen im Grundgebirge von Galicien (Nordwest-Spanien), Geotekt. Forsch., Heft 6, pp. 13—36.

CHRISTIE, J. M., 1960. Mylonitic rocks of the Moine thrust-zone in the Assynt region, North-West Scotland. Trans. Edinburgh Geol. Soc., vol. 18, pp. 79—93.

ESKOLA, P., 1921. On the Eclogites of Norway, Krist. Vidensk. Selskab. Skrifter I. Math.-Nat. Wis. Kl., 8, pp. 1—118.

GRUBENMANN, U. and P. NIGGLI, 1924. Die Gesteinsmetamorphose, I, Allgemeiner Teil, Berlin, Gebr. Borntraeger, 539 pp.

IINSINGER, H. F., 1961. The Geology of the Rio Grande Region (Galicia, Spain), Leidse Geol. Med., deel 26, pp. 64—73.

LÓPEZ DE AZCONA J. M. et al., Mapa geológico de España (1: 50.000), Inst. Geol. y Min. de España, Madrid.
1948. Explicación de la hoja 21, La Coruña, 101 pp.
1949. Explicación de la hoja 6, San Salvador de Serantes (La Coruña), 50 pp.
1952. Explicación de la hoja 20, Sisargas (La Coruña), 28 pp.
1953. Explicación de la hoja 261, Tuy (Pontevedra), 94 pp.
1955. Explicación de la hoja 67, Mugía (La Coruña), 42 pp.
1956. Explicación de la hoja 298, La Guardia (Pontevedra), 37 pp.

LOTZE, F., 1945. Einige Probleme der Iberischen Meseta, Geotekt. Forsch., Heft 6, pp. 1—12.

—— 1956. Das Präkambrium Spaniens. N. Jahrb. Geol. Pal. Mon.h. B., pp. 373—380.

MEHNERT, K. R., 1960. Ueber endogene Erzbildung und ihre Beziehungen zur Granitentstehung durch selektive Mobilisation, N. Jahrb. Min., Abh., Bd. 94, pp. 49—76.

NAVARRO ALVARGONZALEZ, A. and J. DEL VALLE DE LERSUNDI, 1959. Bosquejo geológico de la mitad Norte de la Provincia de Pontevedra, Notas y Comun. del Inst. Geol. y Min. de España, no. 53, pp. 87—106.

PARGA PONDAL, I. and E. TORRE ENCISO, 1953. Sobre una relación entre los tipos de disyunción de los granitos gallegos y su historia geológico-tectónica, Notas y Comun. del Inst. Geol. y Min. de España, no. 32, pp. 3—33.

—— et al. Mapa geológico de España (1: 50.000), Inst. Geol. y Min. de España, Madrid.
1953. Explicación de la hoja 44, Carballo (La Coruña), 100 pp.
1953. Explicación de la hoja 43, Lage (La Coruña), 76 pp.
1954. Explicación de la hoja 260, Oya (Pontevedra), 28 pp.

—— 1956. Nota explicativa del mapa geológico de la parte N. O. de la provincia de la Coruña, Leidse Geol. Med., deel 21, pp. 468—484.

SAMPELAYO, P., 1922. Criaderos de Hierro de España, IV. Hierros de Galicia, Mem. Inst. Geol. y Min. de España, Madrid.

SCHULZ, G., 1835. Descripción geognóstica del Reino de Galicia acompañada de un mapa petrográfica de este pais, Madrid, 38 pp.

SITTER, L. U. DE, 1956. Voorlopige resultaten van de kartering in N. Spanje en Z. Frankrijk verkregen in 1955. Leidse Geol. Med., deel 21, pp. 449—466.

—— and H. J. ZWART, 1957. Voorlopige resultaten van de kartering in Noord-Spanje, Leidse Geol. Med., deel 22, pp. 77—95.

TILLEY, C. E., 1925. A preliminary survey of metamorphic zones in the southern Highlands of Scotland, Q. Jour. Geol. Soc. London, vol. 81, pp. 100—110.

—— 1936. The paragenesis of kyanite-eclogites. Miner. Mag., vol. 24, pp. 422—432.

TRÖGER, W. E., 1959. Die Granatgruppe: Beziehungen zwischen Mineralchemismus und Gesteinsart, N. Jahrb. Min. Abh., Bd. 93, pp. 1—44.

TURNER, F. J. and J. VERHOOGEN, 1960. Igneous and Metamorphic Petrology, 2nd ed. McGraw-Hill, New York.

WOLFF, T. VON, 1942. Methodisches zur quantitativen Gesteins- und Mineral Untersuchung mit Hilfe der Phasenanalyse (ausgeführt am Beispiel der mafischen Komponenten des Eklogits von Silberbach), Tscherm. Min. Pet. Mitt. Bd. 54, pp. 1—120.